

Applying opportunistic observations to model current and future suitability of the Kopet Dagh Mountains for a Near Threatened avian scavenger

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Abstract

Many avian species are in danger of extinction due to anthropogenic activities and climate change. Human activities have led to eradication of many natural habitats and climate change has altered species distribution especially in mountainous habitats. In the present study, we used distribution records of a Near Threatened avian scavenger, bearded vulture (*Gypaetus barbatus*) that were collected through 9 years of opportunistic observations and modeled its distribution in the Khorasane-Razavi Province in Iran. We also assessed the impacts of future climate change on the distribution of this species. Our results show that most suitable habitats for Bearded vultures are in the northern regions of the Khorasane-Razavi province. The most important variables affecting the distribution of the bearded vulture were the annual precipitation (37.5% contribution), landcover (22% contribution), and distance to road (16.2% contribution). Our results also showed that around 80% to 91% of the species' suitable habitats will decrease due to climate change in the future. Suitable habitats of the species that are predicted to remain suitable in the future should be prioritized for conservation. Human activities like road expansion should be avoided in areas with high suitability for this species. This study stresses the need for action to conserve this vulture in the Khorasan-e-Razavi province, and beyond its borders.

Keywords

Gypaetus barbatus, distribution modeling, climate change, conservation, Iran

Introduction

A large number of species are endangered due to anthropogenic activities and climate change.^{1,2} During the last few decades, human activities caused habitat loss and declines in the populations of many species.² Climate change has been identified as a major factor in predicting species extinctions and changes in their habitat distribution in the next few decades.^{3–5} Successful conservation programs depend on adequate knowledge of the species' ecology, distribution and a recognition of their major threats. Obtaining this information is difficult in far-ranging species with long life spans, such as vultures.⁶

Worldwide, vulture populations have dramatically decreased over the last few decades.^{6–8} These declines are attributed to reduced availability of breeding habitat and food, as well as poisoning linked to poaching and agricultural practices.^{9–11} Bearded vulture (*Gypaetus barbatus*), a cliff nesting birds of prey, is among the threatened species of vultures and listed as Near Threatened.¹² The species is widely distributed across the Palearctic, Afrotropical and Indomalayan regions.^{13–17} Its principle food is carrion and even further the diet of bearded vultures consists 80% to

90% of bones.¹² Unlike other vultures that feed their offspring through regurgitation, bearded vultures carry the remains of the prey to their nests using their talons.^{18,19}

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Young chicks up to 2 months are not yet able to digest bones and need meat.

The bearded vulture population has decreased significantly across most of its distribution range.^{20,21} This species is listed Vulnerable in Europe²² and its breeding habitats have vastly decreased.²³ The species decline in the Western Europe is due to human disturbances either directly through attacking and killing adult birds and destroying their eggs²⁴ or indirectly through food poisoning, powerline collisions and reduction in breeding due to increased human disturbance.²⁵ The most important threatening factors for this species include scarcity of food resources, illegal use of poisoned carcasses for predator control (to eradicate wolves, foxes, jackals, and crows),²⁰ habitat fragmentation, breeding reduction,²⁶ and poaching. Bearded vulture became extinct in the Alps in 1913, with the last bird shot in the Italian valley, Aosta. In Sardinia the last birds disappeared in the 1960s. Only in the Pyrenees and on Corsica did bearded vultures remain extant. In the remaining Balkans, bearded vultures disappeared and all but in Crete the species were extinct by 2000. In several reintroduction projects on Europe, the species is currently making a comeback in the Alps, Andalusia and the mountain chains between the Alps, Pyrenees, and Andalusia.

Bearded vulture is a widespread resident avian species that occurs in high mountains throughout Iran. The species is listed as threatened species in the country. While there are many efforts for conservation of bearded vulture in other parts of its distribution range,¹² very little is known about the species distribution, ecology, and population size in Iran. This vulture is included in the list of Iran's protected species but because its ecology remains unknown conservation planning for the species is hampered by this lack of information. Thus, in this study, we used data from 9 years of opportunistic observations to model the species habitat suitability in Khorasan-e-Razavi province and identify the environmental drivers of its distribution. Since assessing the impacts of climate change was proposed as necessary measure for successful conservation of the species,¹² and recent predictions have shown that climate change could be a major threat to Iran's biodiversity,²⁷ we studied the impact of climate change on bearded vulture's distribution.

Materials and methods

Study area

Khorasan-e-Razavi province is the fourth largest province in Iran with an area of 118,854 km². It is located between the latitudes of 33° and 53' to 37° and 42' and longitudes of 52° and 19' to 61° and 16'. This province has an arid and semi-arid climate with the highest and lowest elevation of 3211 and 300 m above the sea level. Khorasan-e-Razavi contains a great diversity of vertebrates due to high climatic and habitat diversity.^{28,29} This province contains five of eight habitat types that are proposed for birds in Iran³⁰ as follow: true desert and semi-desert, semi-arid steppe of the desert rim and foothills, high mountains, forests and woodland, and wetlands. A large proportion of Khorasan-e-Razavi province is covered by Kopet Dagh Mountains (approximately 21% of the province). Kopet Dagh mountain ranges with a length of 650 km and width

of 100 km is located along the two countries of Iran (3.3% of the country) and Turkmenistan.

Distribution data and environmental variables

Since the species occupies remote mountainous areas,¹² collecting distribution records for this species could be a challenging task in some parts of its distribution range. Because there are many remote mountainous areas with poor road developments in Iran, distribution data on this species are scarce. In this study, distribution records (24 points) of the species were obtained from 9 years (2010–2018) of opportunistic observations during unregular wildlife monitoring program in the Khorasan-e-Razavi province (Figure 1). These monitoring programs cover the whole province and include all wildlife species, the results of some of which have been presented elsewhere.^{31–33} We recorded the species presence in Khorasan-e-province using Garmin S84 with an error of less than 5 m.

We used climatic, topographic, land cover and anthropogenic variables related to the species ecology^{12,15,34} for building the species distribution model (Table 1). Land cover and anthropogenic variables were acquired from Forests, Range and Watershed Management Organization in Iran. In order to equalize the layers, the Euclidean distances of all pixels were calculated using ArcGIS 9.3. Climatic variables were downloaded from WorldClim.³⁵ Altitude were obtained from the Shuttle Radar Topography Mission (SRTM) elevation model (<http://srtm.csi.cgiar.org>).³⁶ We calculated slope using the method from the terrain function in Raster package.³⁷

Species distribution modeling

We used MaxEnt 3.4.1³⁸ for modeling habitat suitability of bearded vulture. MaxEnt (Maximum Entropy Modeling) is one of the best methods among many algorithms for modeling species distribution patterns^{39–41} and was successfully applied in modeling avian distribution.^{42–44} This method only needs presence data from the species and is very effective even when distribution data is scarce.⁴⁵ MaxEnt was run with maximum iterations of 1000, convergence threshold of 0.0001 and 1000 background points. In this study 80% of distribution records were used for training and 20% were used for the test run.

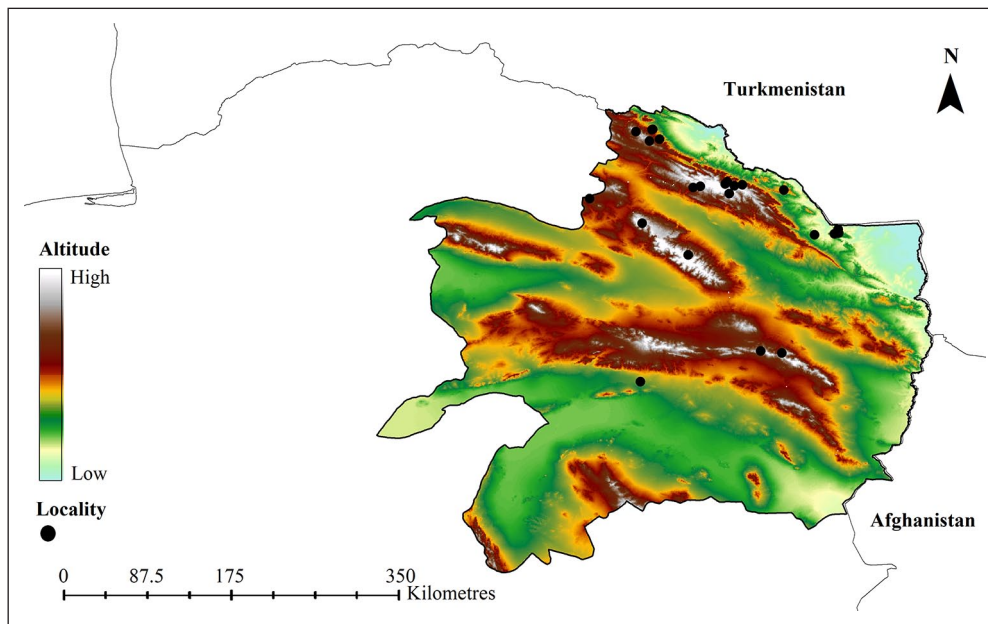
In order to evaluate the models, we used Area Under the ROC Curve (AUC). AUC is a widely used method to evaluate species distribution model's performance.^{46–48} An inappropriate model without good predicting power has an AUC of 0.5 and a model with powerful prediction capabilities would have an AUC equal to 1.⁴⁹

Predicting the impacts of climate change

To assess the impacts of climate change on the distribution of bearded vultures in Khorasan-e-Razavi, two general circulation models of MIROC5 and GISS-E2-R for 2070 (average for 2061–2080) were used. One representative concentration pathways (RCP 8.5) was used from each general circulation model. The following climatic variables

Table 1. Variables used in modeling of bearded vulture (*Gypaetus barbatus*) distribution.

Variables	Definition	References
Topography	Altitude above the sea level slope	(SRTM) elevation model
Climate	Mean diurnal range (Bio2), temperature seasonality (Bio4), mean temperature of the most wet quarter (Bio8), annual precipitation (Bio12), precipitation seasonality (Bio15), precipitation of the coldest quarter (Bio19)	WorldClim
Land cover	Agricultural lands with two categories (irrigated and non-irrigated) and rangelands with three categories of range type 1 (rangelands with more than 50% canopy cover), range type 2 (rangelands with 25%–50% canopy cover) and range type 3 (rangelands with 5%–25% canopy cover)	Forests, Range and Watershed Management Organization
Anthropogenic	Distance to the road Distance to human settlements	Forests, Range and Watershed Management Organization

**Figure 1.** Study area along with distribution records of bearded vulture (*Gypaetus barbatus*).

were used: mean diurnal range, temperature seasonality, mean temperature of wettest quarter, annual precipitation, precipitation seasonality and precipitation of the coldest quarter for current and future climatic conditions. All variables were obtained from Worldclim. MaxEnt 3.4.1. was used to model the distribution of bearded vultures based on climatic variables and projected it into the future. In order to quantify the impacts of climate on the habitats of the bearded vulture we first converted continuous model outputs to presence/absence maps using 10th percentile training presence threshold.⁵⁰ Then calculated area of suitable habitats under current and future climatic conditions using Raster package³⁷ in R environment v. 3.4.3.⁵¹

Results

The result of assessing MaxEnt model performance showed that AUC was equal to 0.951 for the training and 0.893 for the test data which shows a pretty good prediction of habitat distribution of bearded vulture in our study area. Our model shows that suitable habitats for the bearded vulture in Khorasan-e-Razavi is located in north and northeastern parts of this region. Other areas of Khorasan-e-Razavi

contains habitats with moderate suitability for this species as well (Figure 2).

We found that annual precipitation with a contribution of 37.5% landcover with a 22% contribution, and distance to road with 16.2% contribution, were the most important variables in determining the distribution of bearded vultures in our study area (see Table 2 for contribution of all variables).

Habitat suitability for the bearded vultures was positively correlated with annual precipitation, distance from the road and temperature seasonality while its distribution was negatively correlated with mean temperature of wettest quarter and precipitation seasonality. For the landcover, range type 2 which is rangelands with 25% to 50% canopy cover was the most suitable for bearded vulture (Figure 3).

Climate change

Result from assessing the performance of climate-only models showed an AUC of 0.933 for the training and 0.921 for test data. This shows a good prediction ability of the species model. Our study of the effects of climate change on suitable habitats for bearded vultures in the Kopet Dagh Mountains using two general circulation

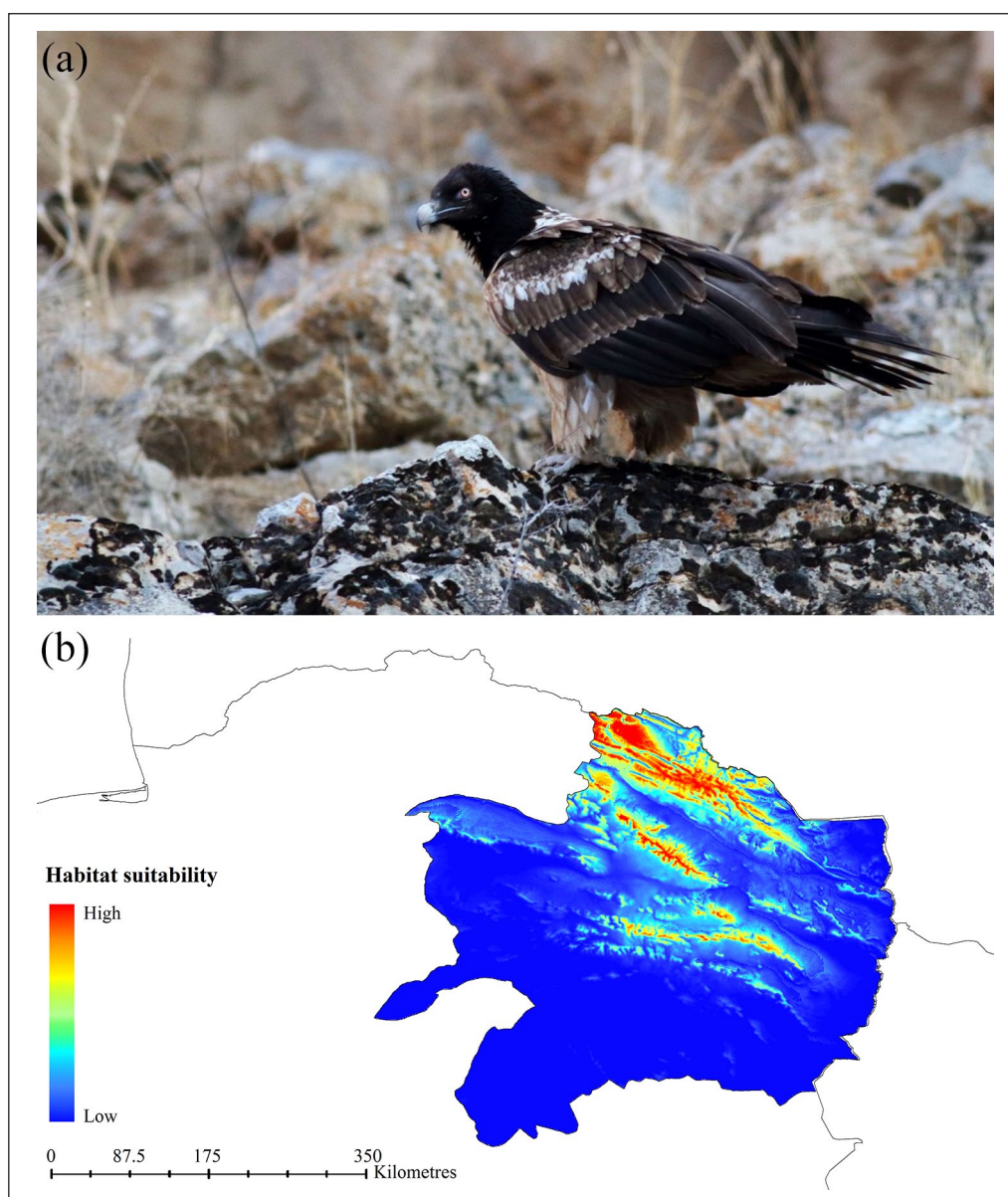


Figure 2. Bearded vulture (*Gypaetus barbatus*) in its natural habitats (a), habitat suitability model of bearded vulture in Khorasan-e-Razavi province (b). Bearded vulture photographed by Ali Khani.

Table 2. The contribution of variables used for modeling the habitat selection of bearded vulture (*Gypaetus barbatus*).

Variable	Percent contribution
Annual precipitation	37.5
Landcover	22
Distance to roads	16.2
Precipitation seasonality	10
Mean temperature of the most wet quarter	5.7
Temperature seasonality	2.6
Slope	1.8
Distance to human settlements	1.2
Mean diurnal range	1
Precipitation of the coldest quarter	1
Altitude	1

models (MIROC5, GISS-E2-R) showed that this species will lose a large portion of its suitable habitats in the future under RCP 8.5 (Figure 4). Current suitable habitat of the species is 21,058 km² (17.7% of the study area) but will decrease to 4879 km² (3.5% of the study area, relative change = $3.5/17.7 - 1 = -80\%$) based on GISS-E2-R model and 1892 km² (1.59% of the study area, relative change = $1.59/17.7 - 1 = -91\%$) based on MIROC5. The highest loss of suitable habitats would be in the northern parts of Khorasan-e-Razavi province and the central areas will not change considerably.

Discussion

Vultures are among the most threatened birds throughout the world.^{6,8} Their population diminished or was eliminated

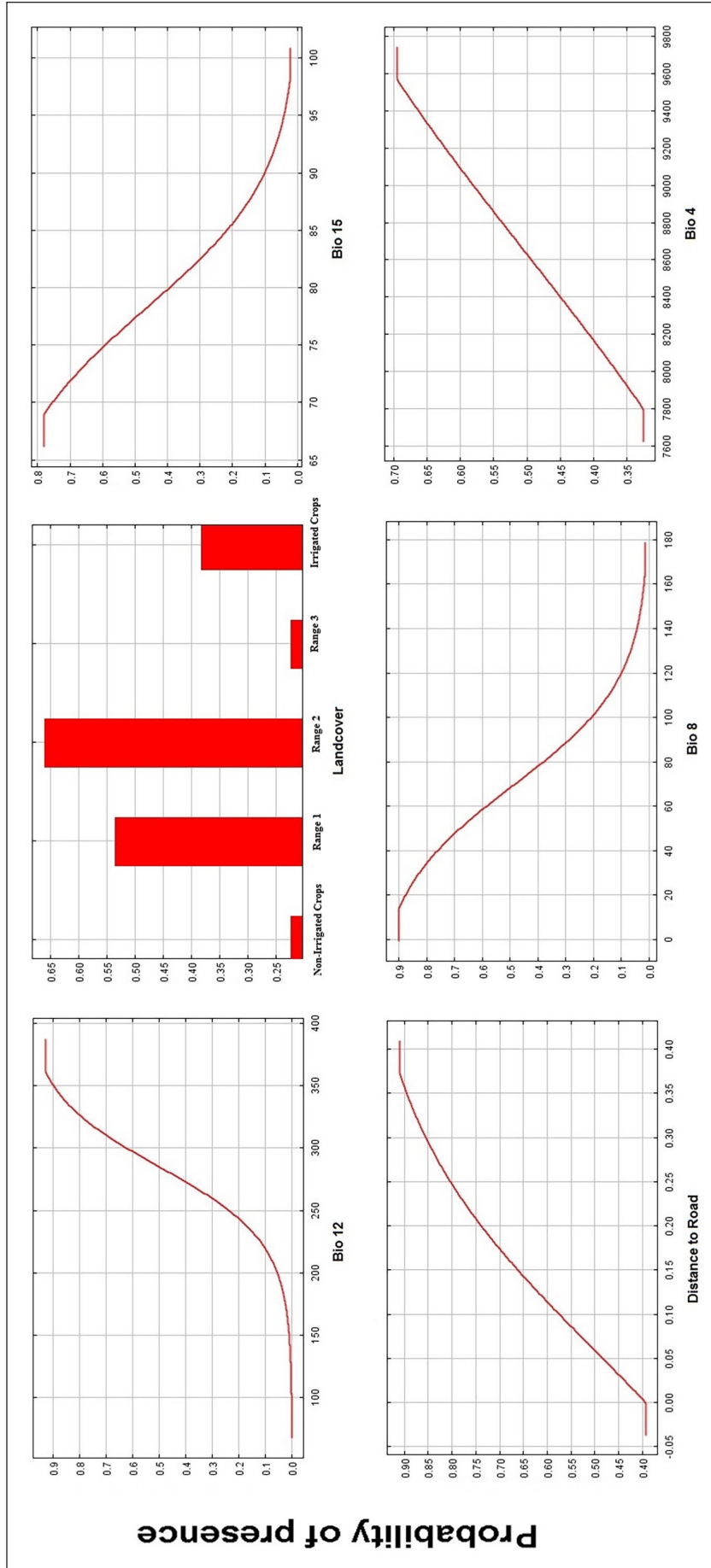


Figure 3. Response of bearded vulture (*Gypaetus barbatus*) to the environmental variables. Range type 1 (rangelands with more than 50% canopy cover), range type 2 (rangelands with 25%–50% canopy cover) and range type 3 (rangelands with 5%–25% canopy cover).

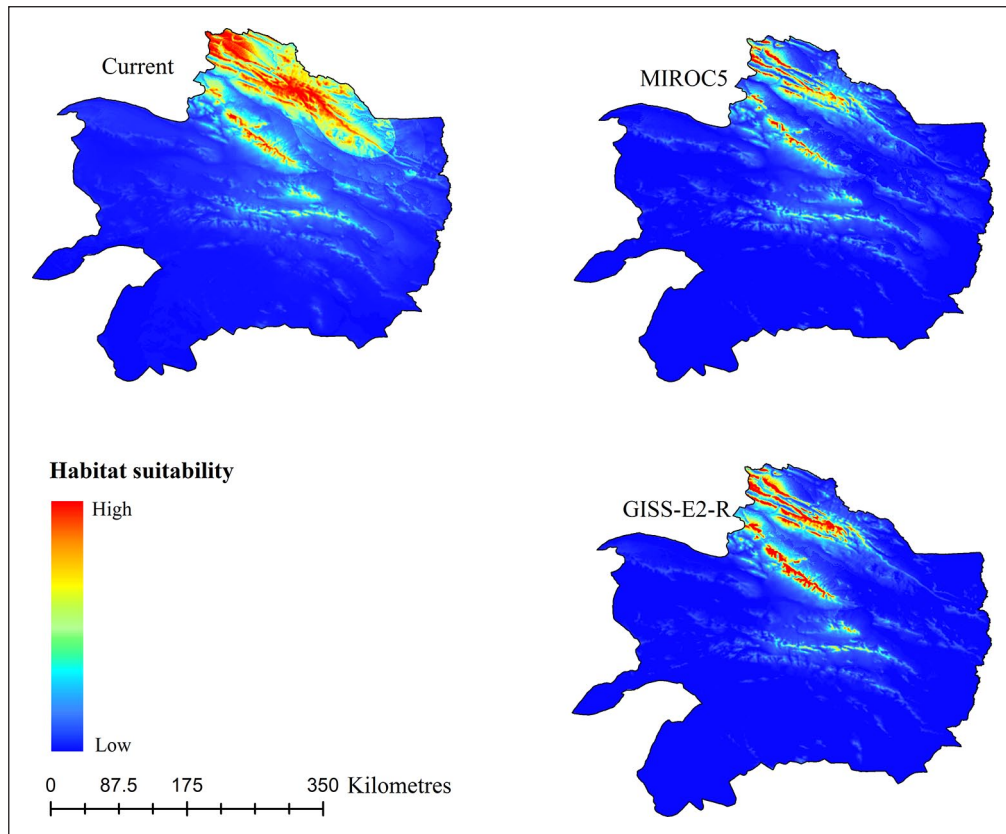


Figure 4. Bearded vulture (*Gypaetus barbatus*) distribution under current and future (MIROC5 and GISS-E2-R) climatic condition in Khorasan-e-Razavi province.

in some of their distribution regions due to habitat loss and lack of food resources,^{9–11} exposure to livestock contaminated with drugs, direct persecution like poison or shooting. The bearded vulture, one of the most prominent species among the vultures, has suffered population reductions in many of its distribution regions and proceeded to the level of being endangered or locally extinct.^{20,21,52–54} In this paper, distribution pattern of the species as well as important environmental variables in defining its distribution in northeastern Iran was studied for the first time.

According to our results, annual precipitation was among the important variables affecting distribution of bearded vultures. This might be due to the effects of annual precipitation on habitat productivity. The highest increase in habitat suitability was when annual precipitation increased from 200 to 350 mm. This variable has also been identified as one of the most important factors in determining the winter distribution of MacQueen's bustard *Chlamydotis macqueenii* in Iran.⁵⁵ However, the effect of annual precipitation was different for the two species such that increase in precipitation was linked to habitat suitability reduction for MacQueen's bustard but habitat suitability increase for bearded vultures. The main habitats of bearded vulture are high altitude grasslands and steep pastures at different life stages.^{53,56} In this study, we showed that rangelands with canopy cover between 0.25 to 0.5 were the most important factor among the land cover variables in predicting the species presence. This might be the dominant vegetation cover in mountainous

areas of Khorasan-e-Razavi that could provide food resources to bearded vultures due to less condensed vegetation. Bearded vultures are searching for food visually and fly close to mountain slopes or over the ground to look for leftovers of bones and parts of carcasses.¹² This searching method is only possible in open landscapes.¹²

Human activities are responsible for habitat loss and population decline in many species during the last decades.² Habitat reduction and loss due to changes in land use is one of the important factors in declining the bearded vulture's population in its distribution range.¹² Road density around this species habitats exhibits presence of humans and anthropogenic disturbances that could lead to reduction of survival and breeding rates of bearded vulture.^{57,58} In this study, we demonstrated that with increase in distance from the road, habitat suitability for the presence of bearded vultures will increase. This shows the negative impacts of road construction on habitat suitability for this species.

Climate change is predicted to lead to the extinction of species and alterations of their distribution range in the next few decades.^{3–5,59} In this study, we showed that the suitable habitats for bearded vultures will decrease in the future. Unfortunately, temperature in habitats of this species is rapidly increasing due to climate change.⁵³ Bearded vulture is in particular very sensitive to climate change for having a long life span, low population density and breeding rate and habitat restrictions to mountainous regions.⁶⁰ In addition, climate change affects the species' food sources by altering distribution of other vertebrate species²⁷ like wild goat and

wild sheep⁶¹ which their bones are important food source for the species.¹²

Species presence records that are now becoming increasingly available via online databases (Global Biodiversity Information Facility, eBird, VertNet, etc.) helping researchers to map species' distribution and habitat suitability. But for some species limited number of presence records are available making it difficult to develop robust models for them. Systematic survey is expansive and not always possible especially in remote regions, thus opportunistic observations can be very useful in filling gaps in our knowledge about species distribution. Many researchers applied opportunistic data to study species' distribution and ecology.^{62–64} For example, Lin et al.⁶⁴ showed that using opportunistic data based on their proposed approach can improve performance of species distribution models. Here we highlighted the importance of opportunistic observations in studying habitat suitability of a globally Near Threatened vulture and in quantifying the impacts of climate change on this iconic species.

Conservation implications

Bearded vulture is an important umbrella species meaning that any action for conservation of the species will be useful for other co-occurring species. Regarded as an umbrella species, it is not only an important species for conservation, but also for the protection of biodiversity in Alpine ecosystems in general.⁶⁵ Therefore, modeling habitat suitability for this species can be used as a base map for expanding conservation plans for this species as well as other wildlife species in the mountainous habitats in northeastern Iran, one of the major biodiversity hotspots in Iran. Moreover, since increasing public awareness and attracting their support is very important for protecting umbrella species, highly suitable habitats can be used as a target for training local and rural people for conserving biodiversity in mountainous habitats in Khorasan-e-Razavi. This can reduce the pressure of anthropogenic threats as an important factor in habitat selection of this species in suitable habitats of this species and prioritize protection of these areas of the species distribution. As our results in this study implicates, future road expansion and construction should be avoided in areas with high suitability for this species.

Suitable habitats for bearded vultures will significantly decrease (80%–91%) in the Khorasan-e-Razavi province. While this is very concerning, considering the difficulty of decreasing the rate of climate change globally in a short time, focusing conservation efforts on the populations of bearded vulture in suitable habitats of this species in central areas and northern regions of the province that are predicted to remain suitable in the future is important in long term survival of the species in Iran's mountains. This study stresses the need for action to conserve this Near Threatened and rare species in the Khorasan-e-Razavi province, and beyond its borders.

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